To appear in J.E.T.P.

SINGLE Z' PRODUCTION AT CLIC BASED ON $e^- \gamma$ COLLISIONS

D. V. Soa[a], **H. N. Long**[b1], **D. T. Binh**[c], and **D. P. Khoi**[c,d]

[a] *Department of Physics, Hanoi University of Education, Hanoi, Vietnam*
[b] *Physics Division, NCTS, National Tsing Hua University, Hsinchu, Taiwan*
[c] *Institute of Physics, NCST, Hanoi, Vietnam*
[d] *Department of Physics, Vinh University, Vinh, Vietnam*

Abstract

We analyze the potential of CLIC based on $e - \gamma$ collisions to search for new Z' gauge boson. Single Z' production at $e - \gamma$ colliders in two $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models: the minimal model and the model with right-handed (RH) neutrinos is studied in detail. Results show that new Z' gauge bosons can be observed at the CLIC, and the cross sections in the model with RH neutrinos are bigger than those in the minimal one.

PACS number(s):12.10.-g, 12.60.-i, 13.10.+q, 14.80.-j.

Keywords: Extended gauge models, Z-prime, collider experiments.

1 Introduction

Neutral gauge structures beyond the photon and the Z boson have long been considered as one of the best motivated extensions of the Standard Model (SM) of electroweak interactions. They are predicted in many beyond SM models. One of them is the models based on $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ (3 - 3 - 1) gauge group [1, 2, 3, 4, 5]. These models have some interesting characteristics. First, the models predict three families of quarks and leptons if the QCD asymptotic freedom is imposed. Second, the Peccei - Quinn symmetry naturally occurs in these models [6]. Finally, the characteristic of these models is that one generation of quarks is treated differently from two others. This could lead to a natural explanation for the unbalancing heavy top quark,....

The Z' gauge boson is a necessary element of the different models extending the SM. In

[1] On leave from Institute of Physics, NCST, Hanoi, Vietnam

general, the extra Z' boson may not couple in a universal way. There are, however, strong constraints from flavour changing neutral current processes specifically limiting non-universal between the first two generations. Low limits on the mass of Z' following from the analysis of variety of popular models are found to be in the energy intervals 500 - 2000 GeV [7, 8].

Recently there are some arguments that the 3 - 3 - 1 models arise naturally from the gauge theories in space time with extra dimensions [9] where the scalar fields are the components in additional dimensions [10]. A few different versions of the 3 - 3 - 1 model have been recently proposed [11].

Recent investigations have indicated that signals of new gauge bosons in models may be observed at the CERN LHC [12] or Next Linear Collider (NLC) [13, 14]. In [15], two of us have considered single production of the bilepton and shown that with the integrated luminosity $L \simeq 9 \times 10^4 fb^{-1}$ one expected several thousand events. In this work, single production of new Z' gauge boson in the 3 - 3 - 1 models is considered. The paper is organized as follows. In Section 2 we give a brief review of two models: relation among real physical bosons and constraints on their masses. Section 3 is devoted to single production of the Z' boson in the $e - \gamma$ collisions. Discussions are given in Section 4.

2 A review of the 3 - 3 - 1 models

To frame the context, it is appropriate to briefly recall some relevant features of two types of 3 - 3 - 1 models: the minimal model proposed by Pisano, Pleitez and Frampton (PPF) [1, 2] and the model with RH neutrinos (FLT) [4, 5].

2.1 The minimal 3 – 3 – 1 model

The model treats the leptons as the $\mathrm{SU}(3)_L$ antitriplets [1, 2, 16] †

$$f_{aL} = \begin{pmatrix} e_{aL} \\ -\nu_{aL} \\ (e^c)_a \end{pmatrix} \sim (1, \bar{3}, 0), \tag{1}$$

where $a = 1, 2, 3$ is the generation index.
Two of the three quark generations transform as triplets and the third generation is treated differently. It belongs to an antitriplet:

$$Q_{iL} = \begin{pmatrix} u_{iL} \\ d_{iL} \\ D_{iL} \end{pmatrix} \sim (3, 3, -\frac{1}{3}), \tag{2}$$

$$u_{iR} \sim (3, 1, 2/3), d_{iR} \sim (3, 1, -1/3), D_{iR} \sim (3, 1, -1/3),\ i = 1, 2,$$

$$Q_{3L} = \begin{pmatrix} d_{3L} \\ -u_{3L} \\ T_L \end{pmatrix} \sim (3, \bar{3}, 2/3), \tag{3}$$

†The leptons may be assigned to a triplet as in [1], however the two models are mathematically identical.

$$u_{3R} \sim (3,1,2/3), d_{3R} \sim (3,1,-1/3), T_R \sim (3,1,2/3).$$

The nine gauge bosons $W^a(a=1,2,...,8)$ and B of $SU(3)_L$ and $U(1)_N$ are split into four light gauge bosons and five heavy gauge bosons after $SU(3)_L \otimes U(1)_N$ is broken to $U(1)_Q$. The light gauge bosons are those of the Standard Model: the photon (A), Z_1, and $W^\pm$. The remaining five correspond to new heavy gauge bosons Z_2, $Y^\pm$ and the doubly charged bileptons $X^{\pm\pm}$. They are expressed in terms of W^a and B as [16]

$$\begin{aligned}
\sqrt{2}\; W^+_\mu &= W^1_\mu - iW^2_\mu, \sqrt{2}\; Y^+_\mu = W^6_\mu - iW^7_\mu, \\
\sqrt{2}\; X^{++}_\mu &= W^4_\mu - iW^5_\mu.
\end{aligned} \tag{4}$$

$$\begin{aligned}
A_\mu &= s_W W^3_\mu + c_W \left(\sqrt{3}\; t_W\; W^8_\mu + \sqrt{1-3\; t^2_W}\; B_\mu\right), \\
Z_\mu &= c_W W^3_\mu - s_W \left(\sqrt{3}\; t_W\; W^8_\mu + \sqrt{1-3\; t^2_W}\; B_\mu\right), \\
Z'_\mu &= -\sqrt{1-3\; t^2_W}\;\; W^8_\mu + \sqrt{3}\; t_W\; B_\mu,
\end{aligned} \tag{5}$$

where we use the following notations: $c_W \equiv \cos\theta_W, s_W \equiv \sin\theta_W$ and $t_W \equiv \tan\theta_W$. The *physical* states are a mixture of Z and Z':

$$\begin{aligned}
Z_1 &= Z\cos\phi - Z'\sin\phi, \\
Z_2 &= Z\sin\phi + Z'\cos\phi,
\end{aligned}$$

where ϕ is a mixing angle.

Symmetry breaking and fermion mass generation can be achieved by three scalar $\mathrm{SU(3)}_L$ triplets Φ, Δ, Δ' and a sextet η

$$\begin{aligned}
\Phi &= \begin{pmatrix} \phi^{++} \\ \phi^{+} \\ \phi^{,0} \end{pmatrix} \sim (1,3,1), \\
\Delta &= \begin{pmatrix} \Delta^{+}_1 \\ \Delta^{0} \\ \Delta^{-}_2 \end{pmatrix} \sim (1,3,0), \\
\Delta' &= \begin{pmatrix} \Delta'^{0} \\ \Delta'^{-} \\ \Delta'^{--} \end{pmatrix} \sim (1,3,-1), \\
\eta &= \begin{pmatrix} \eta^{++}_1 & \eta^{+}_1/\sqrt{2} & \eta^0/\sqrt{2} \\ \eta^{+}_1/\sqrt{2} & \eta'^{0} & \eta^{-}_2/\sqrt{2} \\ \eta^0/\sqrt{2} & \eta^{-}_2/\sqrt{2} & \eta^{--}_2 \end{pmatrix} \sim (1,6,0).
\end{aligned}$$

The sextet η is necessary to give masses to charged leptons [3, 16]. The vacuum expectation value (VEV) $\langle\Phi^T\rangle = (0,0,u/\sqrt{2})$ yields masses for the exotic quarks, the heavy neutral gauge boson (Z') and two new charged gauge bosons (X^{++}, Y^+). The masses of the standard

gauge bosons and the ordinary fermions are related to the VEVs of the other scalar fields, $\langle\Delta^0\rangle = v/\sqrt{2}, \langle\Delta'^0\rangle = v'/\sqrt{2}$ and $\langle\eta^0\rangle = \omega/\sqrt{2},\ \langle\eta'^0\rangle = 0$. In order to be consistent with the low energy phenomenology the mass scale of $SU(3)_L \otimes U(1)_N$ breaking has to be much larger than that of the electroweak scale, i.e, $u \gg\ v,\ v', \omega$. The masses of gauge bosons are explicitly given by

$$m_W^2 = \frac{1}{4}g^2(v^2 + v'^2 + \omega^2),\ M_Y^2 = \frac{1}{4}g^2(u^2 + v^2 + \omega^2), M_X^2 = \frac{1}{4}g^2(u^2 + v'^2 + 4\omega^2), \tag{6}$$

and

$$\begin{aligned} m_Z^2 &= \frac{g^2}{4c_W^2}(v^2 + v'^2 + \omega^2) = \frac{m_W^2}{c_W^2}, \\ M_{Z'}^2 &= \frac{g^2}{3}\left[\frac{c_W^2}{1-4s_W^2}u^2 + \frac{1-4s_W^2}{4c_W^2}(v^2 + v'^2 + \omega^2) + \frac{3s_W^2}{1-4s_W^2}v'^2\right]. \end{aligned} \tag{7}$$

Expressions in (6) yield a splitting between the bilepton masses [17]

$$|M_X^2 - M_Y^2| \leq 3\ m_W^2. \tag{8}$$

Combining constraints from direct searches and neutral currents, one obtains a range for the mixing angle [16] as $-1.6 \times 10^{-2} \leq \phi \leq 7 \times 10^{-4}$ and a lower bound on $M_{Z_2} : M_{Z_2} \geq 1.3$ TeV. Such a small mixing angle can safely be neglected. In that case, Z_1 and Z_2 are the Z boson in the SM and the extra Z' gauge boson, respectively. With the new atomic parity violation in cesium, one gets a lower bound for the Z_2 mass [18]: $M_{Z_2} > 1.2$ TeV.

2.2 The model with RH neutrinos

In this model the leptons are in triplets, and the third member is a RH neutrino [4, 5]:

$$f_{aL} = \begin{pmatrix} \nu_{aL} \\ e_{aL} \\ (\nu_L^c)_a \end{pmatrix} \sim (1, 3, -1/3), e_{aR} \sim (1, 1, -1). \tag{9}$$

The first two generations of quarks are in antitriplets while the third one is in a triplet:

$$Q_{iL} = \begin{pmatrix} d_{iL} \\ -u_{iL} \\ D_{iL} \end{pmatrix} \sim (3, \bar{3}, 0), \tag{10}$$

$$u_{iR} \sim (3, 1, 2/3), d_{iR} \sim (3, 1, -1/3), D_{iR} \sim (3, 1, -1/3),\ i = 1, 2,$$

$$Q_{3L} = \begin{pmatrix} u_{3L} \\ d_{3L} \\ T_L \end{pmatrix} \sim (3, 3, 1/3), \tag{11}$$

$$u_{3R} \sim (3, 1, 2/3), d_{3R} \sim (3, 1, -1/3), T_R \sim (3, 1, 2/3).$$

The doubly charged bileptons of the minimal model are replaced here by complex neutral ones as follows

$$\begin{aligned}\sqrt{2}\, W^+_\mu &= W^1_\mu - iW^2_\mu, \sqrt{2}\, Y^-_\mu = W^6_\mu - iW^7_\mu,\\ \sqrt{2}\, X^o_\mu &= W^4_\mu - iW^5_\mu.\end{aligned} \tag{12}$$

The *physical* neutral gauge bosons are again related to Z, Z' through the mixing angle ϕ. Together with the photon, they are defined as follows [5]

$$\begin{aligned}A_\mu &= s_W W^3_\mu + c_W \left(-\frac{t_W}{\sqrt{3}}\, W^8_\mu + \sqrt{1-\frac{t_W^2}{3}}\, B_\mu \right),\\ Z_\mu &= c_W W^3_\mu - s_W \left(-\frac{t_W}{\sqrt{3}}\, W^8_\mu + \sqrt{1-\frac{t_W^2}{3}}\, B_\mu \right),\\ Z'_\mu &= \sqrt{1-\frac{t_W^2}{3}}\, W^8_\mu + \frac{t_W}{\sqrt{3}}\, B_\mu.\end{aligned} \tag{13}$$

The symmetry breaking can be achieved with just three $\mathrm{SU}(3)_L$ triplets

$$\chi = \begin{pmatrix} \chi^0 \\ \chi^- \\ \chi'^0 \end{pmatrix} \sim (1,3,-1/3), \tag{14}$$

$$\rho = \begin{pmatrix} \rho^+ \\ \rho^0 \\ \rho'^+ \end{pmatrix} \sim (1,3,2/3), \tag{15}$$

$$\eta = \begin{pmatrix} \eta^0 \\ \eta^- \\ \eta'^0 \end{pmatrix} \sim (1,3,-1/3). \tag{16}$$

$$\tag{17}$$

The necessary VEVs are

$$\langle\chi\rangle^T = (0,0,\omega/\sqrt{2}),\ \langle\rho\rangle^T = (0,u/\sqrt{2},0),\ \langle\eta\rangle^T = (v/\sqrt{2},0,0). \tag{18}$$

The VEV $\langle\chi\rangle$ generates masses for the exotic 2/3 and –1/3 quarks, while the VEVs $\langle\rho\rangle$ and $\langle\eta\rangle$ generate masses for all ordinary leptons and quarks. After symmetry breaking the gauge bosons gain masses as

$$m^2_W = \frac{1}{4}g^2(u^2+v^2),\ M^2_Y = \frac{1}{4}g^2(v^2+\omega^2), M^2_X = \frac{1}{4}g^2(u^2+\omega^2), \tag{19}$$

and

$$\begin{aligned}m^2_Z &= \frac{g^2}{4c_W^2}(u^2+v^2) = \frac{m^2_W}{c^2_W},\\ M^2_{Z'} &= \frac{g^2}{4(3-4s^2_W)}\left[4\omega^2 + \frac{u^2}{c^2_W} + \frac{v^2(1-2s^2_W)^2}{c^2_W}\right].\end{aligned} \tag{20}$$

In order to be consistent with the low energy phenomenology we have to assume that $\langle\chi\rangle \gg \langle\rho\rangle, \langle\eta\rangle$ such that $m_W \ll M_X, M_Y$.

The symmetry-breaking hierarchy gives us a splitting between the bilepton masses [19]

$$|M_X^2 - M_Y^2| \leq m_W^2. \tag{21}$$

Therefore it is acceptable to put $M_X \simeq M_Y$.

The constraint on the $Z - Z'$ mixing based on the Z decay is given [5]: $-2.8 \times 10^{-3} \leq \phi \leq 1.8 \times 10^{-4}$, and in this model we have not a limit for $\sin^2\theta_W$. With so small mixing angle, Z_1 and Z_2 are the Z boson in the SM and the extra Z' gauge boson, respectively. From the data on parity violation in the cesium atom, one gets a lower bound on the Z_2 mass in range between 1.4 TeV and 2.6 TeV [18]. Data on the kaon mass difference Δm_K gives a bound [8]: $M_{Z_2} \leq 1.02$ TeV.

3 Z' production in $e^-\ \gamma$ collisions

Now we are interested in the single production of new neutral gauge bosons Z' in $e^-\ \gamma$ collisions

$$e^-(p_1, \lambda) + \gamma(p_2, \lambda') \rightarrow e^-(k_1, \tau) + Z'(k_2, \tau'), \tag{22}$$

where p_i, k_i stand for the momenta and λ, λ', τ, τ' are the helicities of the particles. At the tree level, there are two Feynman diagrams contributing to the reaction (22), depicted in Fig. 1

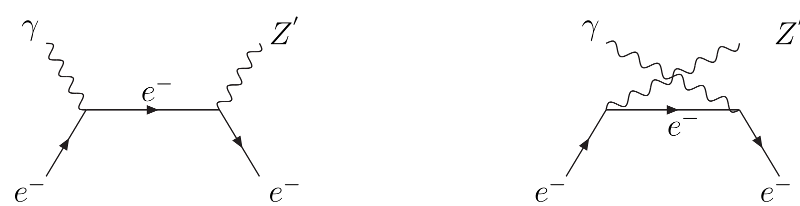

Figure 1: Feynman diagrams for $e^-\gamma \rightarrow Z'\ e^-$

The s - channel amplitude is given by

$$M_s^{Z'} = \frac{ieg}{2c_W q_s^2}\epsilon_\mu(p_2)\epsilon_\nu(k_2)\overline{u}(k_1)\gamma^\nu[g_{2V}(e) - g_{2A}(e)\gamma_5]\not{q}_s\gamma^\mu u(p_1), \tag{23}$$

where $q_s = p_1 + p_2$. The u - channel amplitude is

$$M_u^{Z'} = \frac{ieg}{2c_W q_u^2}\epsilon_\mu(k_2)\epsilon_\nu(p_2)\overline{u}(k_1)\gamma^\nu\not{q}_u\gamma^\mu[g_{2V}(e) - g_{2A}(e)\gamma_5]u(p_1), \tag{24}$$

here $q_u = p_1 - k_2$ and $\epsilon_\mu(p_2)$, $\epsilon_\nu(p_2)$ and $\epsilon_\nu(k_2)$, $\epsilon_\mu(k_2)$ are the polarization vectors of the photon γ and the Z' boson, respectively, $g_{2V}(e), g_{2A}(e)$ are coupling constants of Z' to the electron e. In the minimal model they are given by [16]

$$g_{2V}(e) = \frac{\sqrt{3}}{2}\sqrt{1-4s_W^2}, \quad g_{2A}(e) = -\frac{1}{2\sqrt{3}}\sqrt{1-4s_W^2}, \tag{25}$$

while in the model with RH neutrinos [5]

$$g_{2V}(e) = \left(-\frac{1}{2} + 2s_W^2\right)\frac{1}{\sqrt{3-4s_W^2}}, \quad g_{2A}(e) = \frac{1}{2\sqrt{3-4s_W^2}}. \tag{26}$$

From Eqs. (25) and (26) we see that due to the factor $\sqrt{1-4s_W^2} \ll 1$, the cross sections in the minimal model are smaller than that in the model with RH neutrinos. We work in the center-of-mass frame and denote the scattering angle (the angle between momenta of the initial electron and the final one) by θ. We have evaluated the θ dependence of the differential cross-section $d\sigma/d\cos\theta$, the energy and the Z' boson mass dependence of the total cross-section σ.

i) In Fig. 2 we plot $d\sigma/dcos\theta$ for the minimal model as a function of $cos\theta$ for the collision energy at CLIC $\sqrt{s} = 2733$ GeV [20] and the relatively low value of mass $m_{Z'} = 800$ GeV. From Fig. 2 we see that $d\sigma/dcos\theta$ is peaked in the backward direction (this is due to the e^- pole term in the u-channel) but it is flat in the forward direction. Note that the behaviour of $d\sigma/dcos\theta$ for the model with RH neutrinos is similar at other values of $\sqrt{s}$.

ii) The energy dependence of the cross-section for the minimal model is shown in Fig. 3. The same value of the mass as in i), $m_{Z'} = 800$ GeV is chosen. The energy range is 1200 GeV $\leq \sqrt{s} \leq 3000$ GeV. The curve (a) is the total cross-section for the minimal model, the curves (b) and (c) represent cross-sections of the u, s-channel only, respectively. The curve (d) is the cross-section for the SM model, reduced three times. The u-channel, curve (b) rapidly decreases with $\sqrt{s}$ while the s-channel has a zero point at $\sqrt{s} = m_{Z'}$ then slowly increases. In the high energies limit, the s-channel gives main contribution to the total cross-section. In Fig. 3 the cross-section of the standard model reaches 0.18 pb then slowly decreases to 0.05 pb while the cross-section of the minimal model is only 0.14 pb at $\sqrt{s} = 800$ GeV and 0.05 pb at $\sqrt{s} = 2733$ GeV. The same situation also occurs in the model with RH neutrinos. In this model we fix $m_{Z'} = 800$ GeV and illustrate the energy dependence of the cross-section in Fig. 4. The energy range is the same as Fig. 3, 1200 GeV $\leq \sqrt{s} \leq 3000$ GeV. We see from Fig. 4 that the cross-section σ decreases with $\sqrt{s}$, from σ=0.35 pb down to σ=0.08 pb.

iii) We have plotted the boson mass dependence of the number of events in three models in Fig. 5. The energy is fixed $\sqrt{s} = 2733$ GeV and the mass range is 800 GeV $\leq m_{Z'} \leq 2000$ GeV. As we mentioned above, due to coupling constant, the order of the line of number of events, from bottom to top, is minimal, SM, model with RH neutrinos. The smallest number of events is of the minimal model. With the integrated luminosity $L \simeq 100 fb^{-1}$, the number of events can be several thousands.

In final state $Z^{'}$ will decay into leptons and quarks. Its partial decay width equals [21]

$$\Gamma(Z^{'} \rightarrow f\bar{f}) = \frac{G_F m^2_{Z'}}{6\sqrt{2}\pi} N_c^F [(g^f_{2A})^2 R^f_A + (g^f_{2V})^2 R^f_V] = \begin{cases} 6.4 & \text{GeV for minimal model} \\ 11.8 & \text{GeV for RH neutrinos model.} \end{cases}$$

Due to coupling constants, the lifetime of $Z^{'}$ in the minimal model is longer than that in the model with RH neutrinos.

4 Conclusion

In this paper, we have presented the production of single $Z^{'}$ boson in the $e^-\gamma$ reaction in the framework of the 3 - 3 - 1 models. We see that with this process, the reaction mainly occurs at small scattering angles. The results show that if the mass of the boson is in a range of 800 GeV, then single boson production in $e^-\gamma$ collisions may give observable value at moderately high energies. At CLIC based on $e^-\gamma$ colliders, with the integrated luminosity $L \simeq 100 fb^{-1}$ one expects observable experiments in future colliders. Due to the values of the coupling constants, cross sections in the model with RH neutrinos are bigger than those in the minimal one.

In conclusion, we have pointed out the usefulness of electron - photon colliders in testing the 3 - 3 - 1 models at high energies, through the reaction $e^-\gamma \rightarrow e^- Z'$. If the Z' boson is not so heavy, this reaction offers a much better discovery reach for Z' than the pair production in e^+e^- or e^-e^- collisions.

Acknowledgments: One of the authors (H. N. L) would like to thank Members of Physics Division, National Center for Theoretical Sciences (NCTS), Hsinchu, Taiwan, where this work was completed, for warm hospitality during his visit. His work is supported by the NCTS under grant from National Science Council of Taiwan R. O. C. This work was supported in part by the National Council for Natural Sciences of Vietnam.

References

[1] F. Pisano and V. Pleitez, Phys. Rev. D 46 (1992) 410.

[2] P. H. Frampton, Phys. Rev. Lett. 69, (1992) 2889.

[3] R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Phys. Rev. D 47 (1993) 4158.

[4] R. Foot, H. N. Long and Tuan A. Tran, Phys. Rev. D 50 (1994) R34.

[5] H. N. Long, Phys. Rev. D 53 (1996) 437; Phys. Rev. D 54 (1996) 4691.

[6] P. B. Pal, Phys. Rev. D 52 (1995) 1659.

[7] LEPEWWG $f\bar{f}$ Subgroup, C. Geweriger *et al.*, Preprint LEP2FF/00-03.

[8] H. N. Long and V. T. Van, J. Phys. G 25 (1999) 2319.

[9] I. Antoniadis, K. Benakli and M. Quiros, ETH-TH/01-10, CERN-TH/2001-202, New J. Phys. 3 (2002), 20; T. Li, L. Wei, Phys. Lett. B 545 (2002) 147; S. Dimopoulos, D. E. Kaplan and N. Weiner, Phys. Lett. B534 (2002) 124; I. Gogoladze, Y. Mimura and S. Nandi, Phys. Lett. B554 (2003) 81.

[10] H. Hatanaka, T. Inami and C. S. Lim, Mod. Phys. Lett. A13 (1998) 2601; H. Hatanaka, Prog. Theor. Phys. 102 (1999) 407; G. Dvali, S. Randjibar-Daemi and R. Tabbash, Phys. Rev. D65 (2002) 064021; N. Arkani-Hamed, A. G. Cohen and H. Georgi, Phys. Lett. B513 (2001) 232.

[11] See for example, T. Kitabayshi and M. Yasue, Phys. Rev. D63 (2001) 095002; Phys. Lett. B508 (2001) 85; Nucl. Phys. B609 (2001) 61; Phys. Lett. B524 (2002) 308; L. A. Sanchez, W. A. Ponce and R. Martinez, Phys. Rev. D64 (2001) 075013; W. A. Ponce, Y. Giraldo and L. A. Sanchez, Phys. Rev. D 67 (2003) 075001.

[12] B. Dion *et al.*, Phys. Rev. D 59 (1999) 075006.

[13] P. Frampton, A. Rasin, Phys. Lett. B 482 (2000) 129.

[14] H. N. Long and D. V. Soa, Nucl. Phys. B 601, (2001) 361.

[15] D. V. Soa, T. Inami and H. N. Long, Bilepton production in $e^-\gamma$ collisions, [hep-ph/0304300].

[16] D. Ng, Phys. Rev. D 49 (1994) 4805.

[17] J. T. Liu and D. Ng, Z. Phys. C 62 (1994) 693; N. A. Ky, H. N. Long and D. V. Soa, Phys. Lett. B 486 (2000) 140.

[18] H. N. Long and L. P. Trung, Phys. Lett. B 502 (2001) 63.

[19] H. N. Long and T. Inami, Phys. Rev. D 61 (2000) 075002.

[20] Z. Z. Aydin *et al.*, hep - ph/0208041; R. W. Assman *et al.,* CERN 2000 - 008, p.6 (2000); J. Ellis, E. Keil, G. Rolandi, *Options for Future Colliders at CERN*, CERN- EP/98-03, CERN - SL/98-004 (AP), CERN - TH/98-33.

[21] Particle Data Group, Phys. Rev. D 66 (2002) 010001.

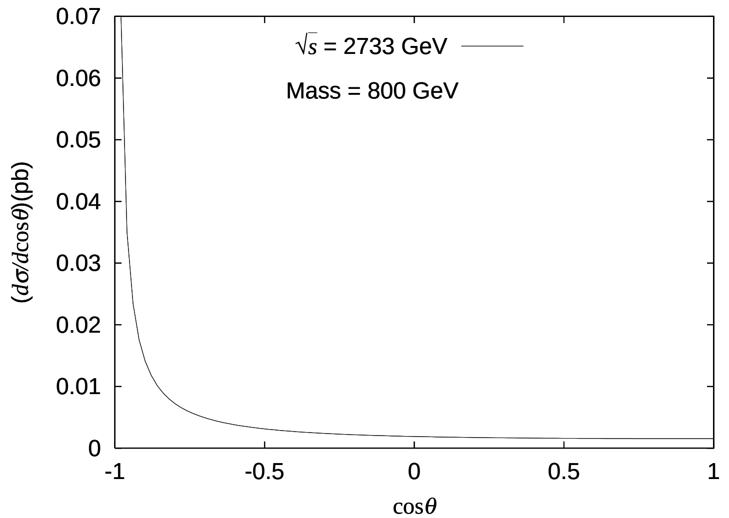

Figure 2: *Differential cross section of the minimal model*

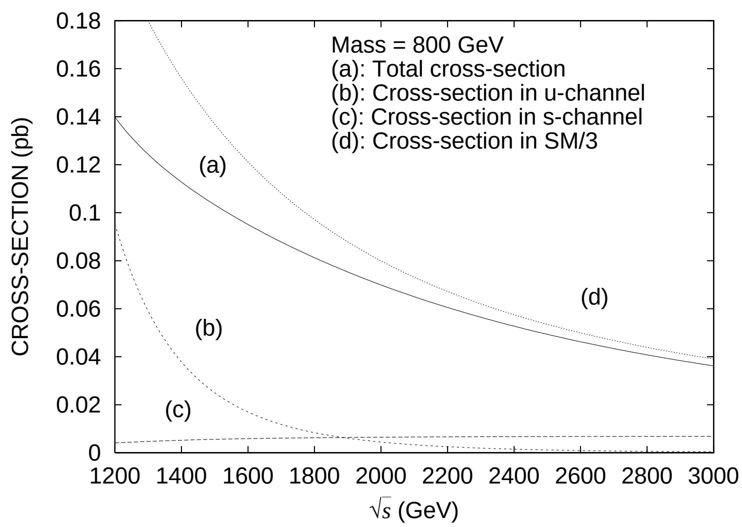

Figure 3: *Cross section* $\sigma(e\gamma \to Z'e)$ *of the minimal model as a function of* $\sqrt{s}$

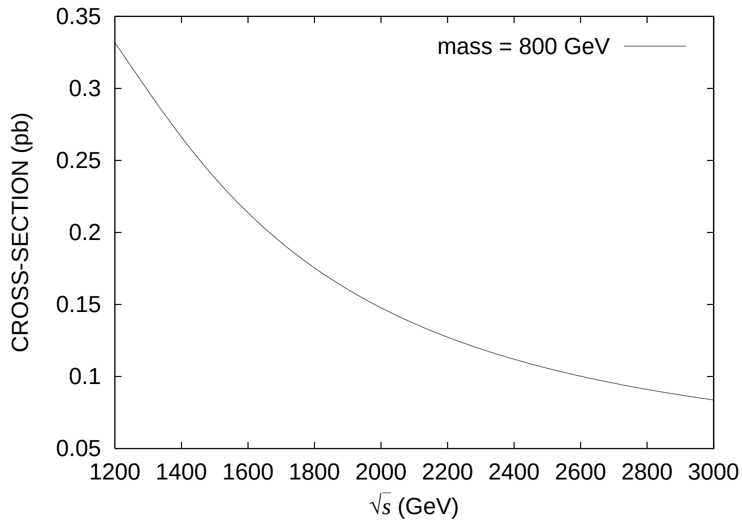

Figure 4: *Cross section* $\sigma(e\gamma \to Z'e)$ *of the model with RH neutrinos as a function of* $\sqrt{s}$

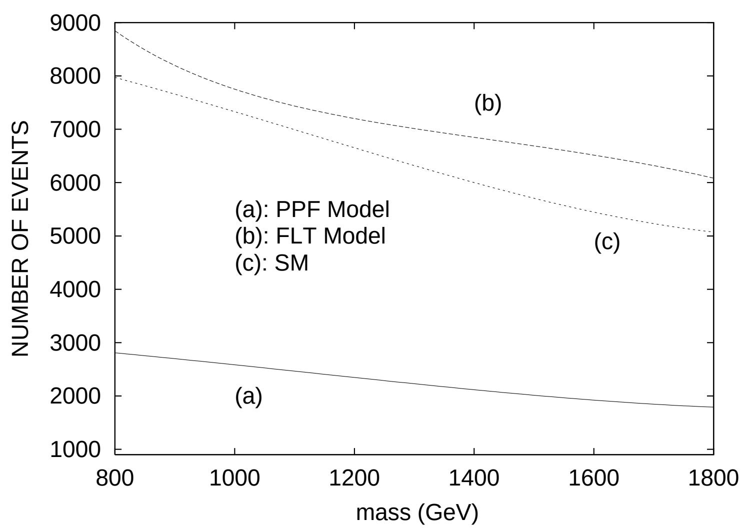

Figure 5: *Number of events of three models*